Jet Propulsion Laboratory
California Institute of Technology

M2020: Bit Holder Assembly

Modeling Local Nonlinearity in Linear Transient Solution

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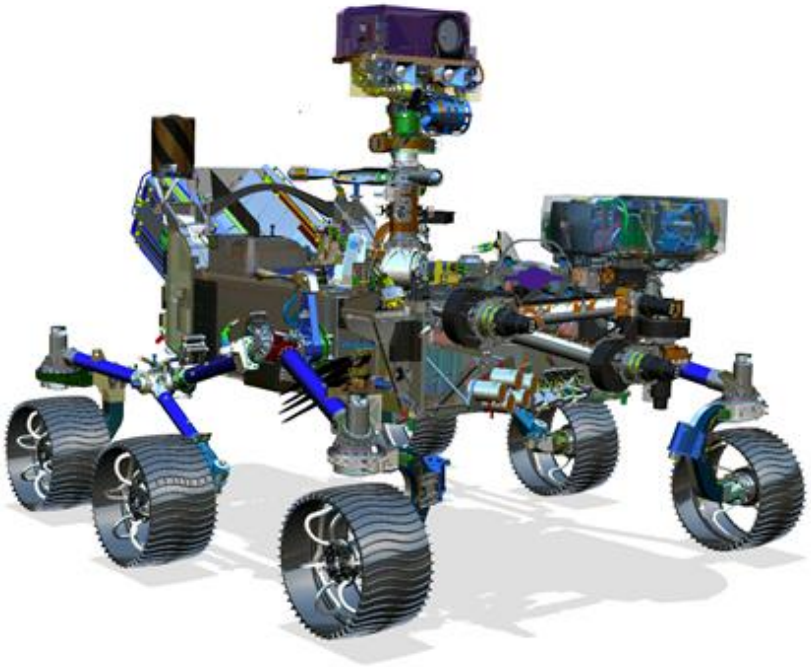
352L Spacecraft Structures and Dynamics

August 2017



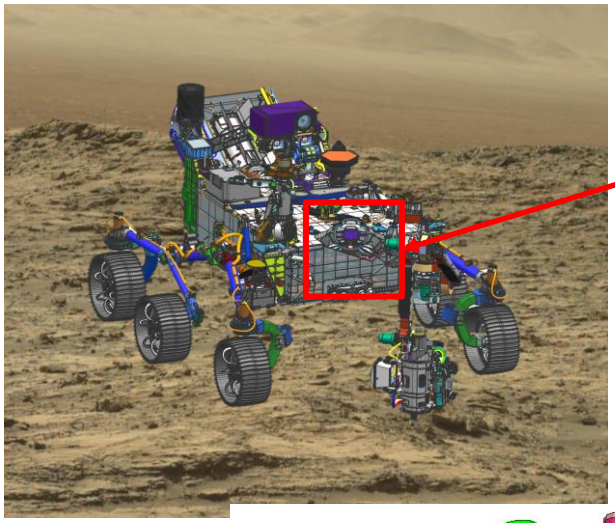
Mars 2020 Project

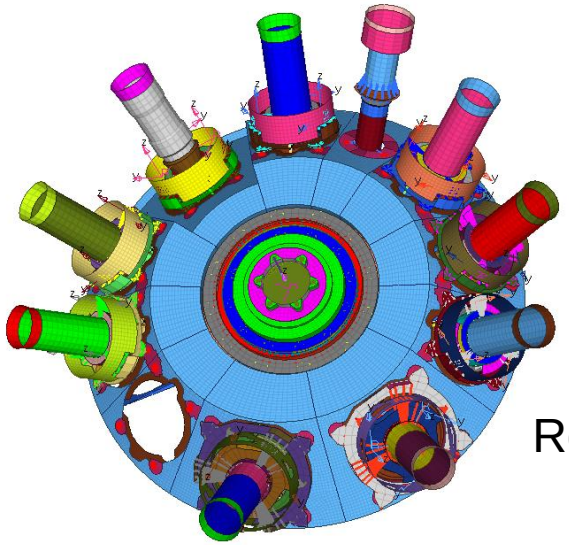
Outline

- Overview of M2020 ACA
  - Bit removal operation
- Motivation for nonlinear dynamic analysis
- Modeling approach and implementation
- M2020 bit holder nonlinear analysis
  - Procedure
  - Sample response for coring bit holder
- Time step size
- Sensitivity study for modeling fidelity
- Summary

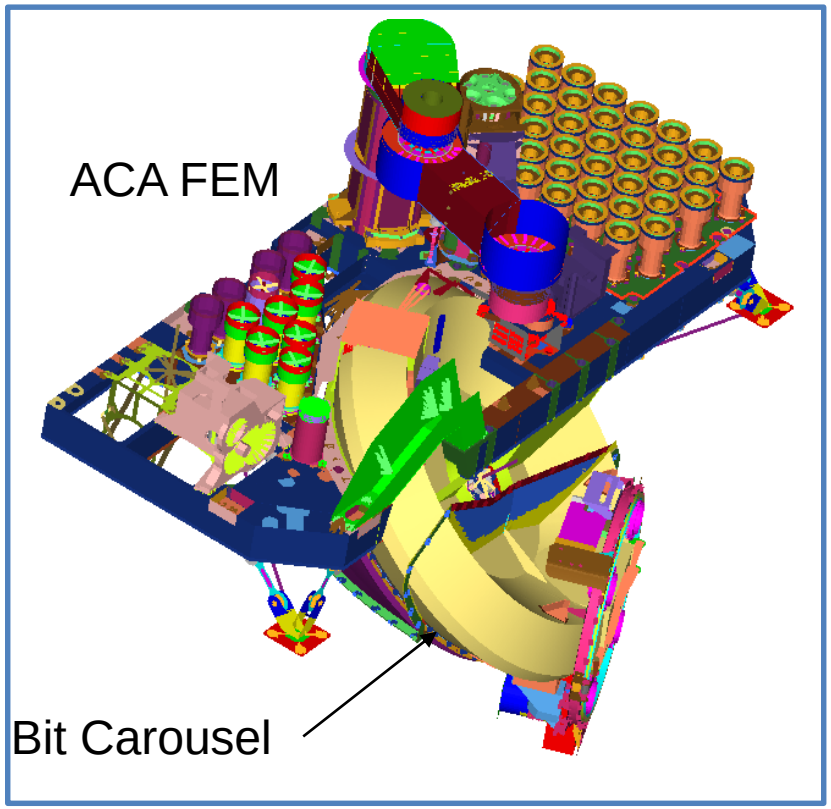
Overview: ACA Carousel

- ACA: Adaptive Caching Assembly



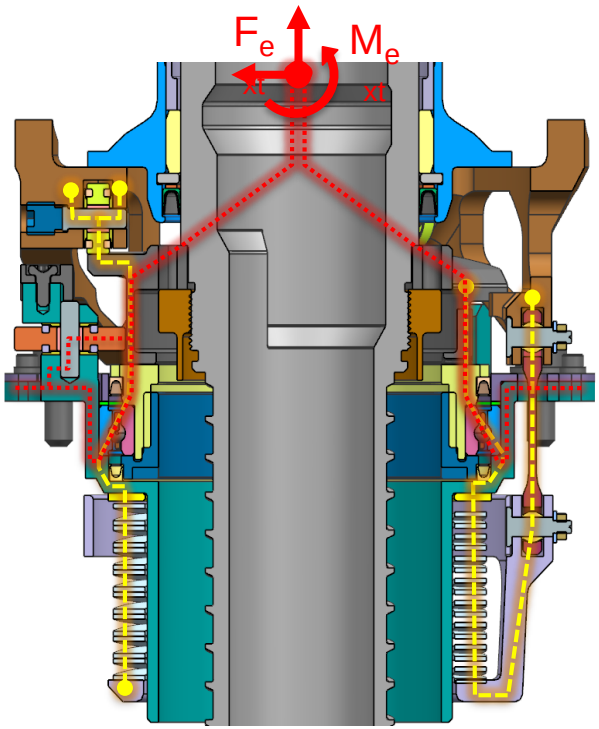


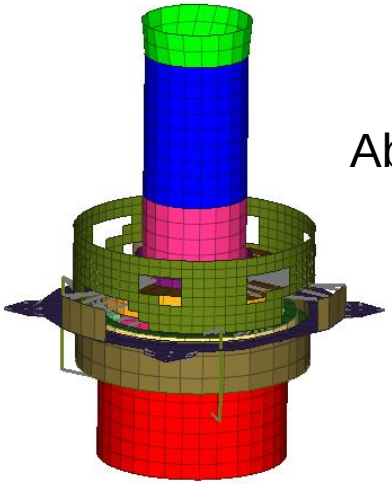
Rotor inside the Bit Carousel



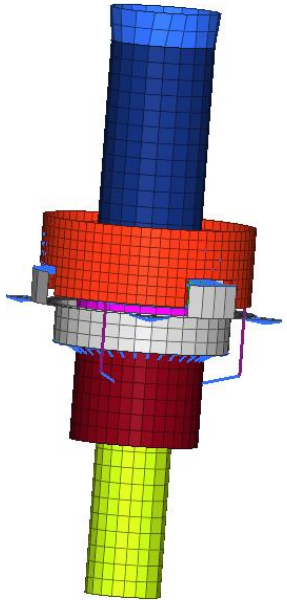
Overview: Bit Holders

- Different bit holders on rotor

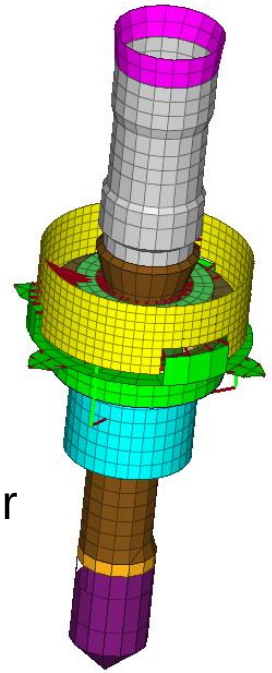




Abrading bit holder

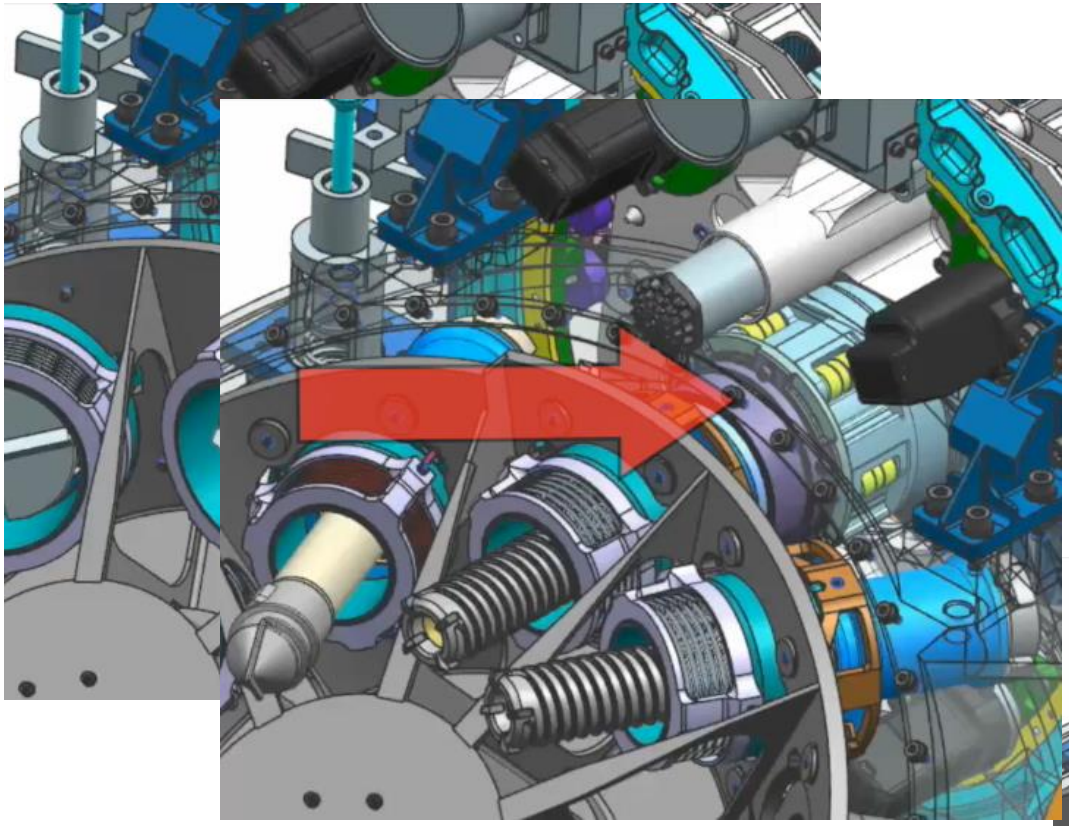


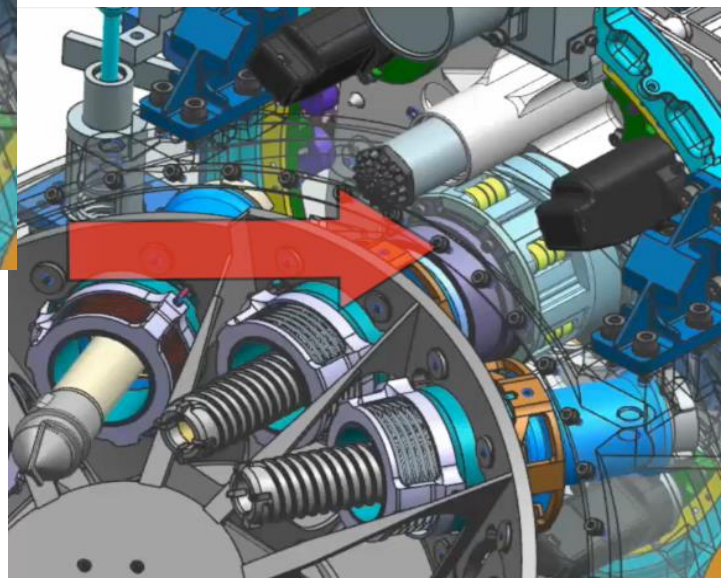
Coring bit holder



Regolith bit holder

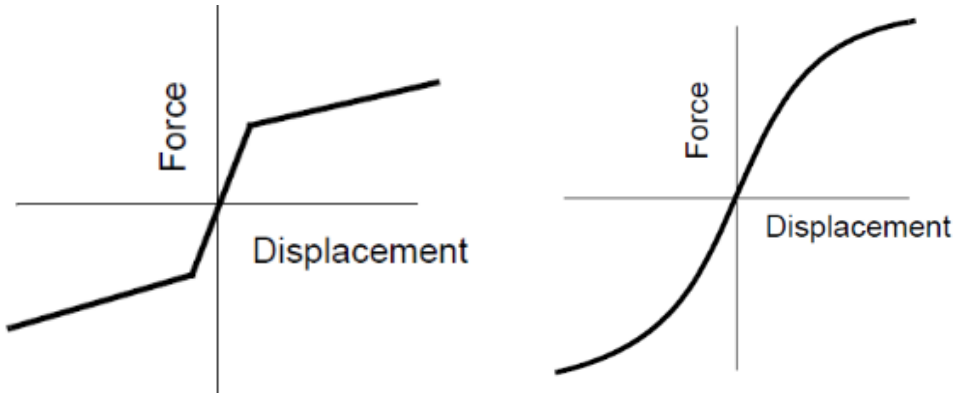
Overview: Bit Removal





Motivation

- Limited spindle torque capability:
  - Limited wave spring preload
  - Potential for uplift during random vibe
- Other problems:
  - Nonlinear springs
  - Constant force devices
  - Structure supported by nonlinear shock isolation systems
- The ability to model local nonlinearities often required for transient loads analysis



Modeling Approach

- Modeling with NOLINs Instead of a general nonlinear solution:

$$\mathbf{M}\ddot{U}(t)+\mathbf{C}\dot{U}(t)+KU(t)=F(t)+N(t-\Delta t)$$

  - Nonlinear force applied at each grid point as an external load
  - Nonlinear force approximated based on the difference between current and previous time step input displacement
    - Time marching solution
    - No iteration to update stiffness matrix → linear solver and faster solution
    - Time step must be small enough to avoid large errors/ convergence issues
- Limitation:
  - Nonlinear elastic only – no load path dependency, geometric nonlinearity, etc.

Implementation

- Direct implementation (Sol. 109)
  - Nonlinear portion of the force directly applied to the grid points
  - Easier to use
- Indirect implementation (Sol. 112) for larger models
  - Nonlinear force must be applied to extra points (EPOINTS)
  - EPOINTS must be tied to the physical grids using transfer functions

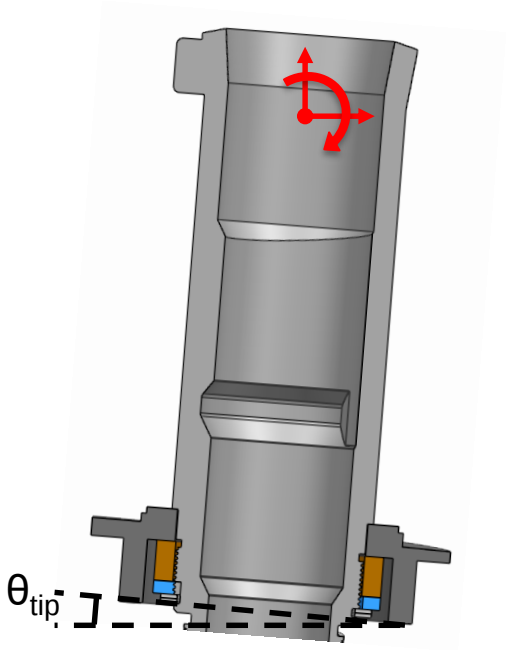
Bit Holder Nonlinear Dynamic Analysis

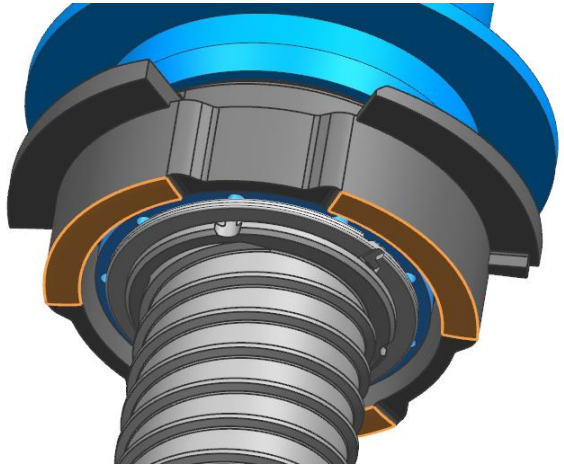
Objective

- Determine the required wave spring stiffness and preload to secure the bit holder in random vibe environment
- Preload must be small enough:
  - Have sufficient spindle torque margin for unlocking a bit (operation)
  - Avoid overly stressed bearing and other components
- Avoiding a large preload may cause bit holders to experience some uplift during random vibe
  - Properly modeling this uplift potential with acceptable accuracy which can be analyzed in a reasonable time

Modeling Approach

- At each contact surface, the bit exchange tang can be separated from the tang seat if the preload is overcome
  - Developing model with NOLIN elements which allow for uplift of the bit exchange tang

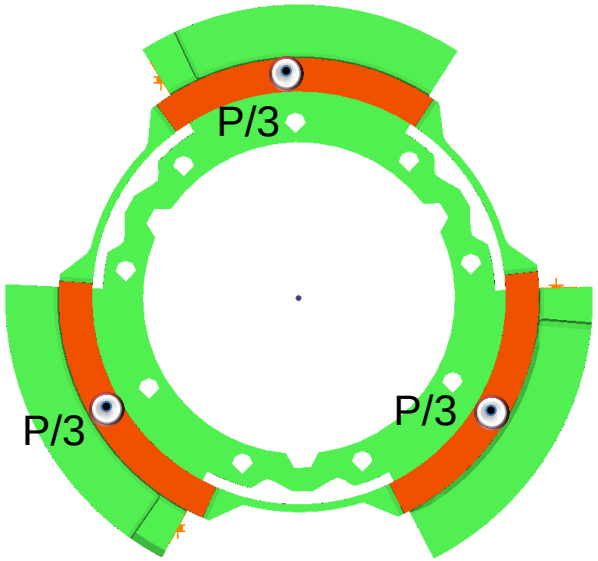


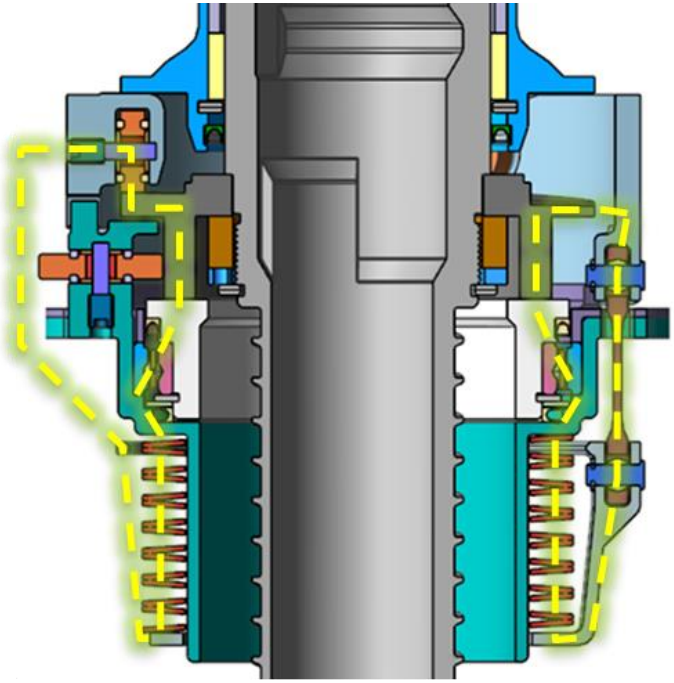


Contact surfaces underneath the bit exchange tang

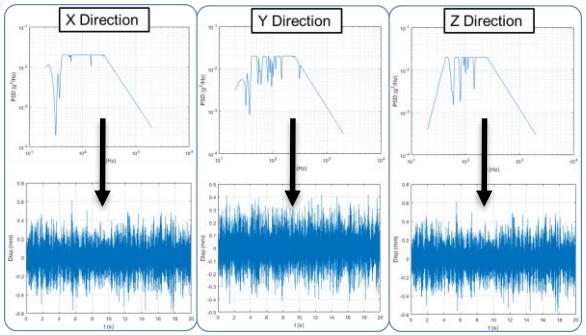
Preload

- Applied through the links and axial rollers to the contact between bit exchange tang and tang seat
  - In FEM, 1/3 of preload is applied to each contact point
- Preload and wave spring stiffness
  - Coring: P=250N, K=17.6N/mm
  - Regolith: P=600N, K=17.6N/mm
  - Abrading: P=250N, K=16.5N/mm

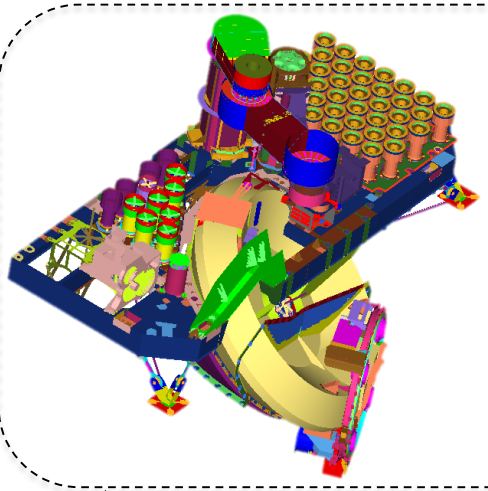




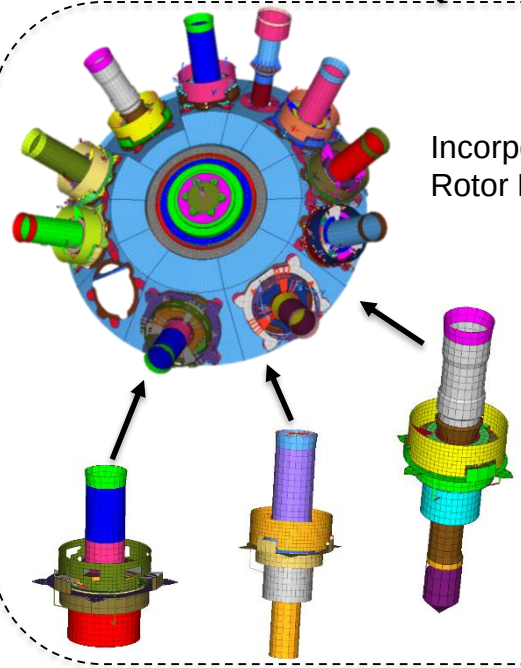
Procedure



A time history input signal is generated from the vibe spec.

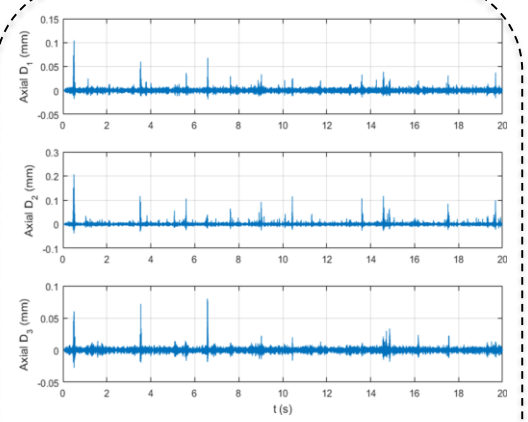


Incorporated into ACA FEM. Random Vibe simulation is run at this level.



Incorporated into Rotor FEM

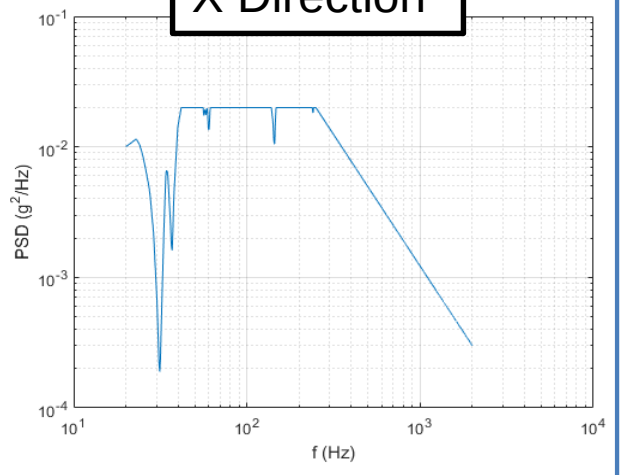
Bit Holder models preload of spring and allows for gapping at Tang-Tang Seat contacts.

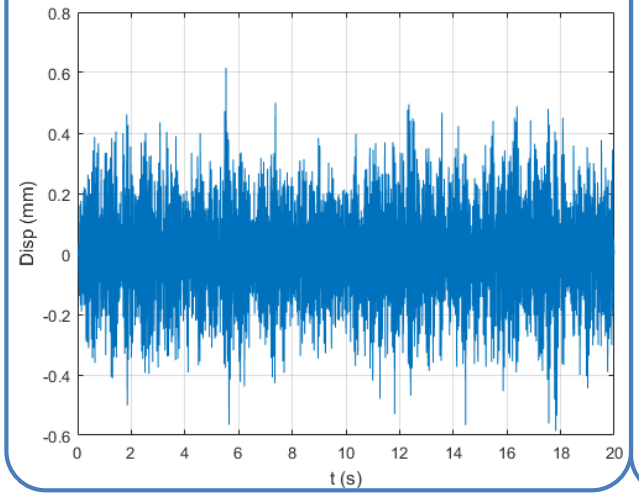


Plots of uplift instances are produced.

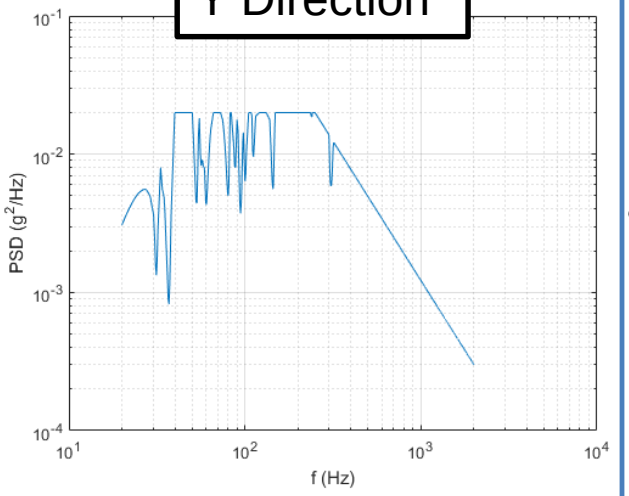
PSD Equivalent Time Histories

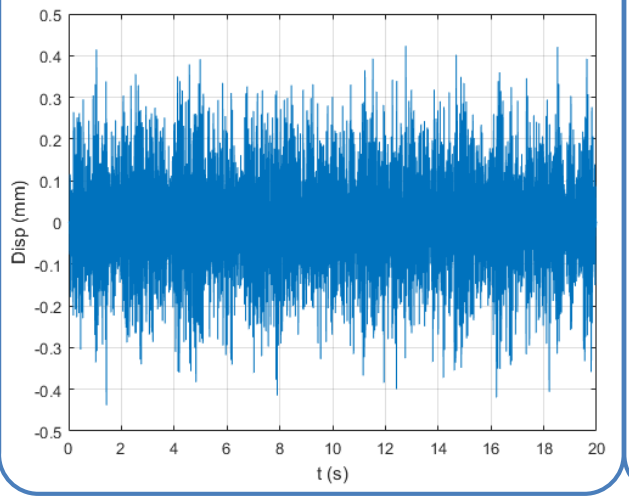
X Direction



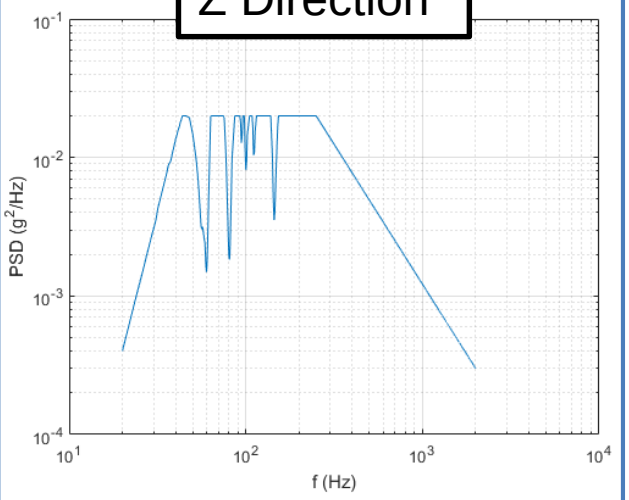


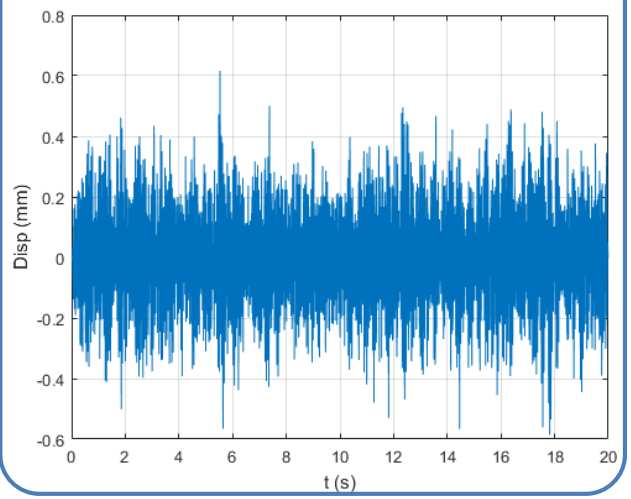
Y Direction



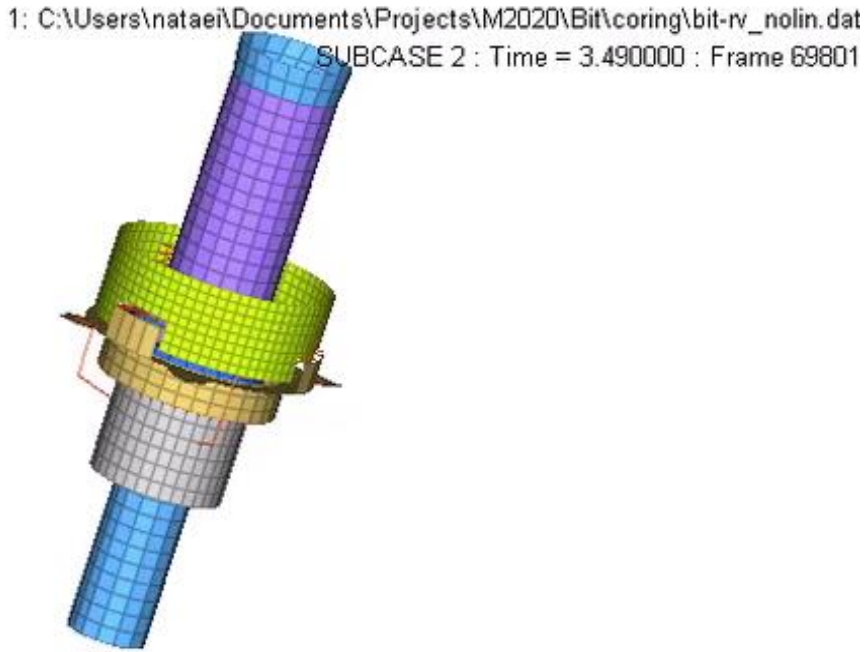


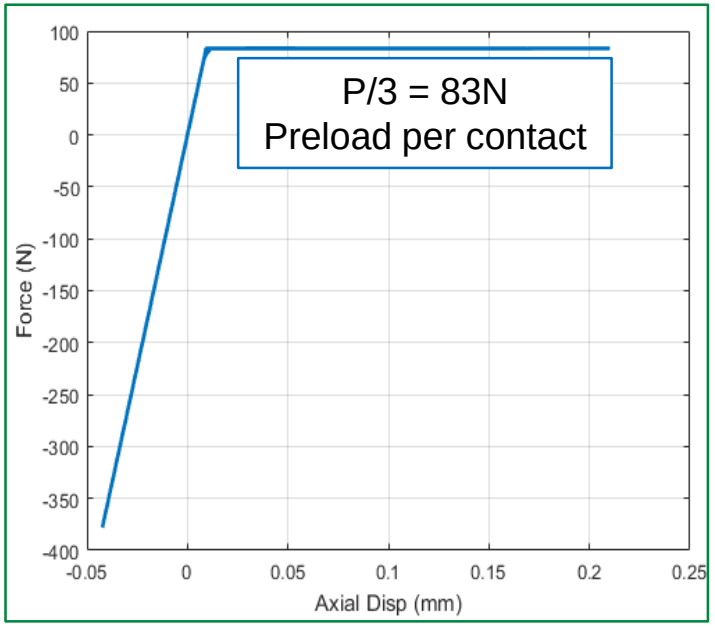
Z Direction





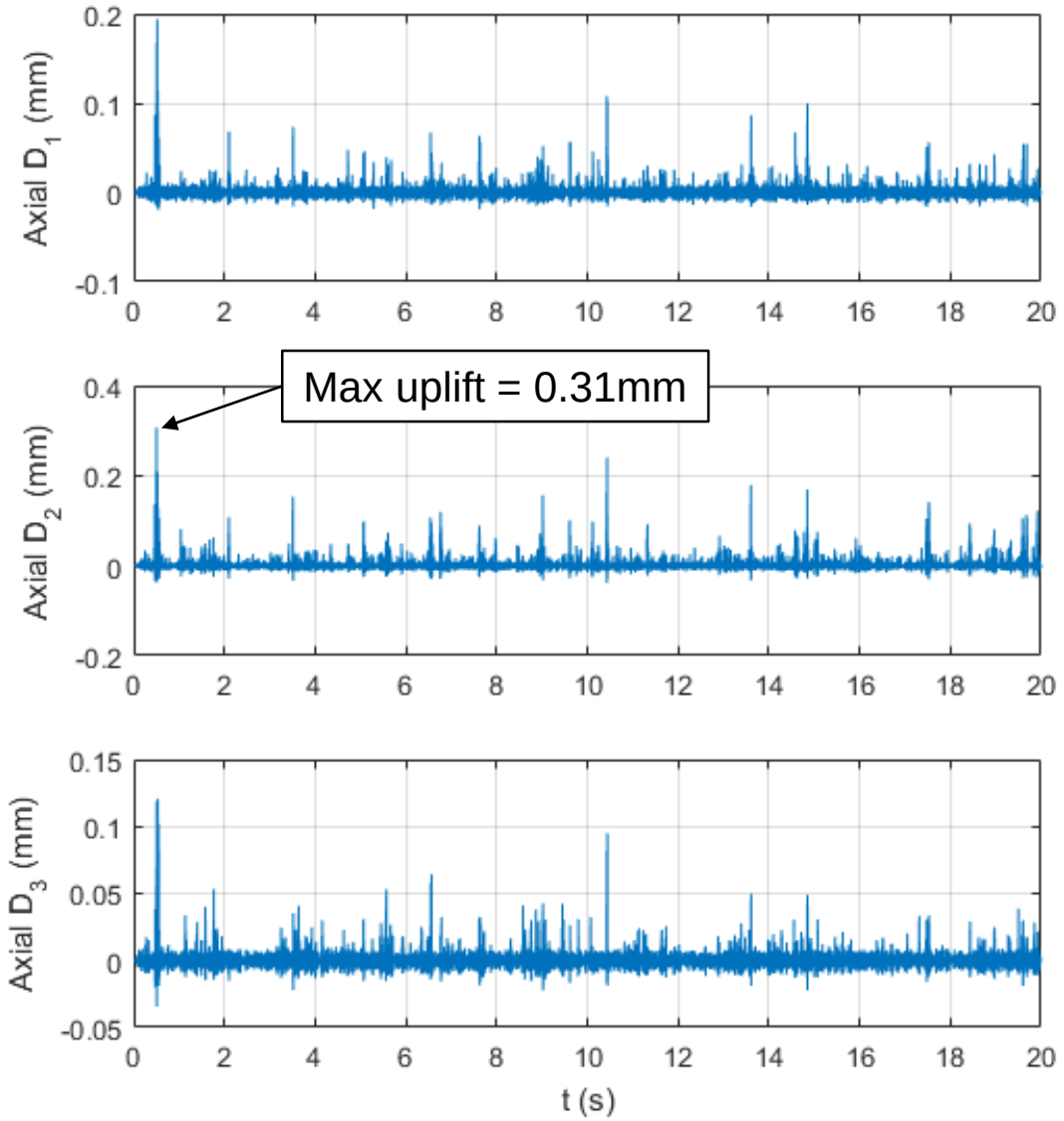
Sample Response





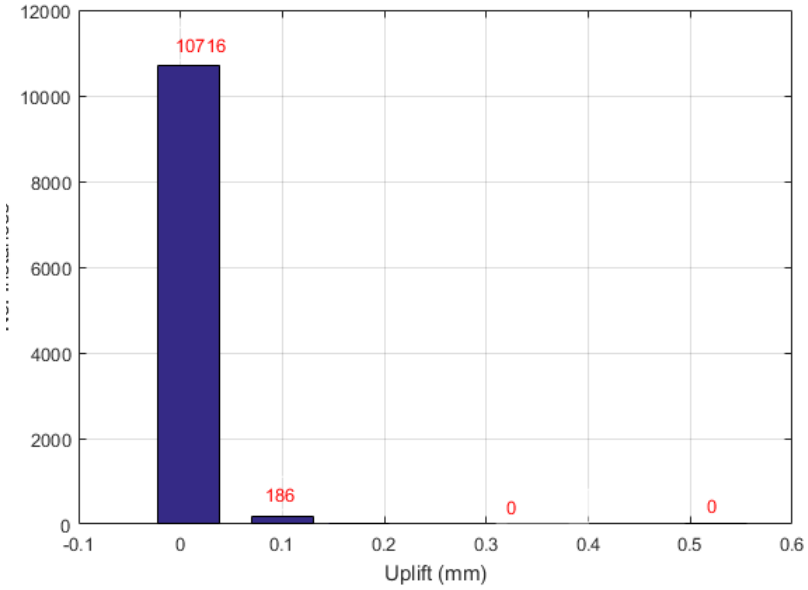
Contact force – deflection

Uplift Time History



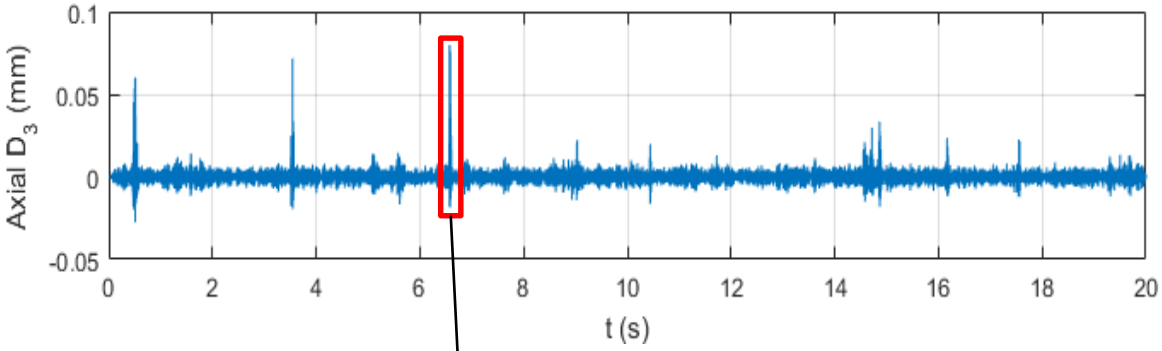
Limit = 0.7mm

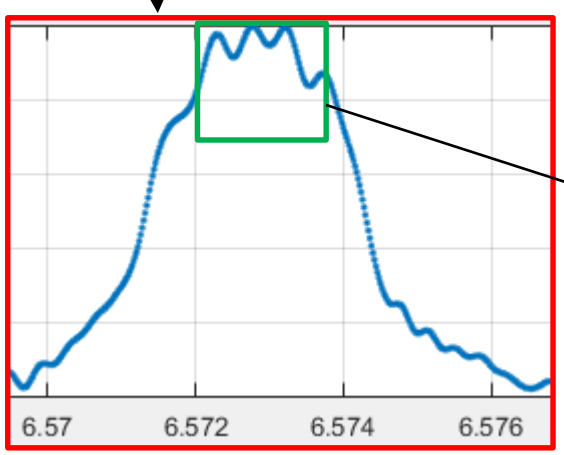
Uplift (% of limit)	No. Instances
<0.1mm	10716
0.1mm ~ 25%	186
25% ~ 50%	54
50% ~ 75%	12
> 75%	0

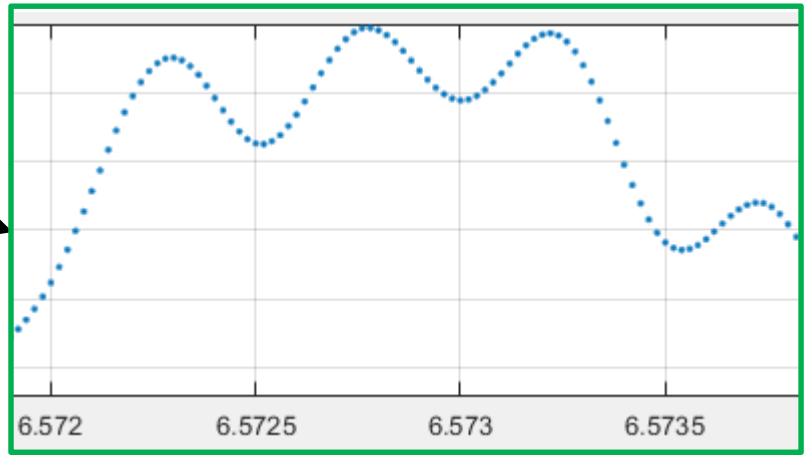


Time Step Size

- Time steps and sampling rates are small enough







Modeling Fidelity

- Breakout coring bit holder model:
  - Decreased mesh size
  - Change of RBEs at contact point
  - Change of contact CBUSH stiffness (*K*)

Simulation	Contacts Displacement RMS (mm)		
	1	2	3
Original	0.0099	0.0141	0.0168
½ Mesh size	0.0098	0.0125	0.0157
¼ Mesh size + Solid elements	0.0098	0.0132	0.0149
RBE	0.0099	0.0141	0.0168
K = 1E+5 N/mm	0.0047	0.0069	0.0091
K = 1E+5 N/mm ½ Mesh size	0.0050	0.0063	0.0092

Summary

- NONLINs: directly applying nonlinearity in a linear algorithm
  - Allow a more computationally efficient solution compared to a general purpose nonlinear analysis
  - Limited to problems with few local elastic nonlinearity
  - Require transfer functions and extra points for implementation in modal transient solution
- Successfully used NOLINs for random vibe analysis of M2020 bit holders
  - Results showed acceptable gapping
  - Contact stiffness deemed the most influential parameter
- Analysis results will be validated by experimental test